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COMPARATIVE DISTRIBUTION AND DIVERSITY OF BATS FROM SELECTED LOCALITIES IN SARAWAK

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ABSTRACT

Surveys on the chiropteran diversity were conducted at eight different localities in Sarawak to document the bat diversity as well as to estimate the composition of bats in these areas. The major finding of bat surveys shows that montane areas have distinct chiropteran composition compared with those in lowland and logged areas. Disturbed habitats do pose a threat to the overall diversity of bats, with the generalist bats been more successful in colonising altered area than those with specialised habitat requirements. Sampling of bats targeted at different site and vegetation type from several protected areas in Sarawak have revealed the current record of bats in Sarawak and its diversity can be monitored for better management of biodiversity in this important region.

Keywords**:** Diversity, chiroptera, forest types, montane, habitat disturbance, Borneo

INTRODUCTION

Borneo holds high chiropteran diversity. There are at least 94 species from eight families that occur in Borneo (Payne *et al.* 1985). Studies on the Bornean chiropteran diversity were pioneered by various authors and these have shaped the current knowledge of this fauna in Borneo. Documentation of mammals in Malaysia, specifically Borneo, has come a long way starting on the 15th century through European travelers, traders, colonial officers, museum collectors, curators and biologist who have documented various species accounts and sightings of mammals in the region (Abdullah 2006). From 1923 to 1932, F.N Chasen and C. Boden Kloss had published several papers documenting mammals in the Peninsular Malaysia, Singapore and Borneo (Abdullah 2006). Later, Chasen published a monograph in 1940 entitled 'A handlist of Malaysian Mammals' in the Bulletin of Raffles Museum which was considered as the primary literature for mammals of the Malay Peninsula, Sumatra, Java, Borneo and their adjacent small islands (Chasen 1940, later revised by Ellerman & Morisson-Scott 1955). Their pioneering works had contributed immensely on our knowledge of the taxonomy and distribution of mammals in this region. From 1938 to 1974, Tom Harrisson and J.E Hill further studied on taxonomy, distribution and ecology of mammals in Borneo (Abdullah 2006). Later, Davis (1958) published a list of mammals from the Kelabit Highlands, followed by Medway (1958), Harrison (1964), Lim (1965), Lim *et al.* (1972), Start (1975), Lim & Muul (1978) and Francis *et al.* (1984). Lord Medway later published a hand list of mammals in Borneo (Medway 1977) and this was later revised in a book entitled 'A field guide to the mammals of Borneo' by Payne *et al.* (1985). All of these studies on mammals from abovementioned scientists have provided an early understanding of the chiropteran diversity in Borneo.

Beginning from the late 1980s to present various bat surveys has been published from various expeditions conducted by local and foreign researchers. Studies from Francis (1989, 1990, 1994), Hall (1996), Nor (1996, 1997) and Tuen *et al.* (2002a, 2002b) have concentrated in Sabah whereas

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Abdullah *et al.* (1997b), Mohd. Azlan *et al.* (2003) and Struebig & Suyanto (2005) conducted bat surveys in Kalimantan province and these have enhanced our knowledge on bat diversity and distribution in Borneo. In Sarawak, Several researchers have been actively documenting bats and their distribution: Abdullah & Hall (1997), Abdullah *et al.* (1997a), Abdullah *et al*. (2000), Hall *et al*. (2002; 2004), Abdullah (2003b), Abdullah *et al*. (2003), Karim *et al*. (2004), Abdullah *et al*. (2005), Mohd. Azlan *et al.* (2005), Jayaraj *et al*. (2005), Anwarali *et al*. (2006a) and Anwarali *et al.* (2008) have collectively recorded many new bat distributions in Sarawak. Although chiropteran diversity in various localities in Borneo has been studied and many surveys have been done especially in limestone areas, there is still a need to document and update new information on bats in Borneo, particularly Sarawak. Thus, the aim of this study is to document bat diversity and distribution in selected localities in Sarawak.

MATERIALS & METHODS

Study Areas

Eight localities that are scattered all around Sarawak were chosen for this study:

1. Tubau camp at Bintulu: The trapping area (<1000 m above sea level (asl)) was a small patch of isolated and disturbed forest. It was concentrated at Busuk Cave, one of the sandstone caves formations that are present at the area. The surrounding area was cleared and planted with *Acacia mangium* seedlings about six months old.
2. Batang Ai National Park: The sampling area was described as secondary forest with patches of orchards [*Garcinia* spp. (mangosteen) and *Durio* spp. (durians)] spanning uphill to a cleared land. The top of the hill was partially cleared and with pioneer plant species covering the floor and some dense palm plots at the edge of the hill. This sampling site was situated near the river (<1000 m asl) that leads to the dam at this national park.
3. Bako National Park: Bako National Park has seven vegetation types and its elevation is at the sea level. The sampling area was focused on two trails where five types of vegetation occurred namely; *kerangas* forest, cliff forest, beach forest**,** mangrove forest, riverine forest and mixed dipterocarp forest. Sampling was also conducted at Pulau Lakei, one of the adjacent islands in Bako National Park. The vegetation of the island is described as *kerangas* forest with shrub land and drier vegetation at the uphill.
4. Mount Penrisen, Padawan: The habitat occurring in the vicinity of the sampling area is described as regenerated forest. The overall vegetation type is described as montane forest which occurs at 1000 m asl. The area has a highland climate, with moderate temperatures ranging from 18°C to 28°C.
5. Kubah National Park: Extensively studied by Hall *et al.* (2004), the area consists of *kerangas* forest and several patches of hill forest with some open areas, streams and banana plots. The sampling was conducted at elevation <1000 m asl mostly near banana plots, a stream and kerangas forest.
6. Similajau National Park: The sampling area is located near the beach where there is mangrove forest. There are three types of vegetation found at the vicinity of the park; mangrove forest, mixed dipterocarp forest and *kerangas* forest (Hazebroek & Abang Morshidi 2000).
7. Lambir Hills National Park: The park is dominated by a series of steep hills in the central and the vegetation consists of mixed dipterocarp forest and *kerangas* forest. The sampling area is situated at the mixed dipterocarp forest <1000 m asl.
8. Mount Murud: Located on the Limbang and Miri Divisions, the vegetation on Mount Murud consists of both lowland forest and montane forest. The sampling was conducted at the montane forest >1000 m asl.

Trapping

Ten to 20 mist nets and one to three four-bank harp traps were deployed at locations that is anticipated to be bat flyways such as across small streams, trails, and also near flowering banana trees. These traps were deployed for at least three consecutive nights to maximise capture and to accumulate species number (Hall *et al.* 2004; Karim *et al.* 2004). Bats were identified using keys from Payne *et al.* (1985) and standard measurements including weight were recorded.

Data Analysis

The species richness in each area was assessed by total number of species caught. Further comparison

was done calculating percentage of species caught with total number of bats found in Borneo. Relative abundance was calculated by total number of individuals per species divided by total number of individuals. Unweighted Pair-Groups Method Average (UPGMA) cluster analysis was also performed to study the similarities of the chiropteran community in the areas and was done following Everitt (1993) using present and absent species data.

RESULTS

Sampling effort totaling of 691 net-nights was done to document bat diversity in the selected localities. Based on the results, there were 45 species from seven families totaling 806 individuals recorded in the selected sampling sites in Sarawak (Table 1). This study documented 48.9 % of the total chiropteran fauna known from Borneo (98 species).

Based on previous studies at similar sites (Start 1972a; Francis *et al*. 1984; Churchill & Zborowski 1985; Hall 1992; Abdullah & Hall 1997; Hall *et al.* 2004; Jayaraj *et al*. 2005; 2006; Anwarali *et al.* 2006a, 2006b, 2008; Fukuda *et al.* 2009) there are at least a total of 62 species of bats that have been recorded from these areas (Table 2). Conversely these areas sustain 66 % of bats recorded in Borneo. A comparison between Payne *et al.* (1985) and museum deposits in UNIMAS Zoological Museum (Abdullah *et al.* 2010) revealed that there are 75 species of bats in Sarawak. Thus these areas record 83 % of total chiropteran that can be found in Sarawak. Conversely this study was unable to document the remaining 13 species of bats that can be found in Sarawak.

Cynopterus brachyotis recorded the highest relative abundance (30.77 %) as this species was recorded at all the sampling sites. *Hipposideros cervinus* recorded the second highest relative abundance (14.02 %) but was not recorded at Mount Murud and Batang Ai National Park. Several species were captured as singletons in this study namely, *Emballonura alecto, E. monticola, Saccolaimus saccolaimus, Megaderma spasma, Nycteris javanica, H. cineraceus, Arielulus cuprosus, Pipistrellus vodermanni* and *Kerivoula hardwickii*. Several new records for Sarawak and for the sampling areas were also added from this study. Out of the 45 species caught, three were new records to Sarawak: *Murina rozendaali* in Anwarali *et al*. (2006), *K. minuta* and *K. intermedia* in Jayaraj *et al*. (2006). There were 68 new species records for the sampled areas when compared with previous records. Forty new records (including new records for Sarawak) were obtained for several areas that did not have previous records on the diversity of bats, notably Tubau camp, Similajau National Park, Batang Ai National Park and Mount Penrisen. UPGMA cluster analysis (Figure 1) revealed that Bako National Park has the most distinct chiropteran composition as it was placed as a solitary cluster. Lambir Hills National Park, Kubah National Park, Similajau National Park and Tubau Camp were placed together in a cluster and, whereas Mount Murud, Batang Ai National Park and Mount Penrisen were placed in another cluster.

Comparison of bat diversity at different elevation from selected areas in Borneo was limited to lowland habitat: Lambir Hills National Park (<1000m asl.), and Kubah National Park (<1000m asl.) versus montane habitat: Mount Murud (>1000m asl.) and Mount Penrisen (1000m asl.). Similarity dendogram showed moderate species diversity difference between lowland (34 species) and montane habitat (21 species). Out of 43 species 22 were confined to lowland habitat, six were confined to higher elevation and 13 were found to be distributed at both elevations. Out of six species that were confined to higher elevation, only two species were found at montane altitudes (i.e. >1000m asl.). One species, *Falsistrellus petersi* which was previously known to be confined to montane areas were recorded at lowland (Kubah National Park).

DISCUSSION

The findings of three new geographic records for Sarawak indicate that the chiropteran diversity in Borneo is still underrepresented and further survey are needed. There are still a lot of forest areas that have not been sampled for bats. All new records for Sarawak were previously recorded in Sabah, indicating that most available references (Payne *et al.* 1985; Corbet & Hill 1992) do not elucidate the accurate distribution record in Borneo. For example, *H. ater* is now found at Bau limestone area (Abdullah *et al.* 2003) and *Chironax melanocephalus* is now found at Kubah National Park (Hall *et al.* 2004). This is because previous studies used by Payne *et al.* (1985) were concentrated on Sabah, and more recent work (Abdullah & Hall 1997; Abdullah *et al.* 1997a, 1997b, 2000a; Hall *et al*. 2002; 2004; Abdullah 2003b; Abdullah *et al*. 2003, 2005; Karim *et al.*

2004; Abdullah *et al*. 2005; Mohd. Azlan *et al*. 2005; Jayaraj *et al*. 2005; Anwarali *et al*. 2006a; 2009) have been focused on Sarawak as new means of accessing areas were becoming available. In terms of distributional records at the sampling sites, a high number of new distributional records in these locations indicate that the information on diversity of bats in these areas were still lacking.

Table 1. List of species caught at eight sampling locations

	TBC	LHNP	SNP	BANP	KNP	MM	MPP	BNP	Relative abundance (%)
Pteropodidae:									
Cynopterus brachyotis	4**	4	16**	70**	40	43	50**	21	30.81
Cynopterus horsfieldii							1**		0.12
Penthetor lucasi				7**	2	6**	8**	37	7.45
Megaerops ecaudatus				3**		18**	4**		3.11
Dyacopterus spadiceus							1**		0.12
Balionycteris maculata	1**	3	1**	2**	5	1**	1**		1.74
Aethalops aequalis						19	4**		2.86
Eonycteris spelaea	sg**		1**				6**	30	4.60
Eonycteris major						5**	3**		0.99
Macroglossus minimus			15**			11	25**	7	7.20
Emballunuridae:									
Emballonura alecto								1	0.12
Emballonura monticola								1**	0.12
Saccolaimus saccolaimus								1	0.12
Megadermatidae:									
Megaderma spasma								1	0.12
Nycteridae:									
Nycteris tragata								1	0.12
Rhinolophidae**:**									
Rhinolophus borneensis	7**	2	3**		1		1**		1.74
Rhinolophus affinis					1**		1**		0.25
Rhinolophus trifoliatus		1	1**		1			4	0.87
Rhinolophus sedulus		12	2**		2				1.99
Rhinolophus luctus								2	0.25
Rhinolophus spp.	sg**								

Hipposideridae:									
Hipposideros ater						3**		1**	0.50
Hipposideros bicolor								8**	0.99
Hipposideros cineraceus								1**	0.12
Hipposideros dyacorum		3	1**		1**			3	0.99
Hipposideros ridleyi		1**	3**		3**				0.87
Hipposideros cervinus	10	64	4**		18		1**	16	14.04
Hipposideros galeritus		22			2			21	5.59
Hipposideros larvatus								57	7.08
Hipposideros diadema		1			1			1	0.37
Vespertilionidae:									
Myotis muricola			1**					1**	0.25
Myotis ater								2**	0.25
Myotis ridleyi		2**	1**						0.37
Myotis horsfieldii					4**				0.50
Arielulus cuprosus			1**						0.12
Hypsugo vordermanni								1**	0.12
Tylonycteris robustula		1**							0.12
Murina rozendaali						3*			0.37
Kerivoula papillosa		1**	2**		1**				0.50
Kerivoula hardwickii		1**							0.12
Kerivoula pellucida		1	1**		1**			1**	0.50
Kerivoula intermedia		2**		1**			1*		0.62
Kerivoula minuta		2**					1*		0.37
Kerivoula spp.	2								0.25
Miniopterus schreibersi						3**			0.37
No. Family	3	4	4	2	4	3	4	7	
No. Species	7	17	15	5	15	10	15	23	
No. Individuals	24	123	53	83	83	112	108	219	
Effort (nets x night)	14	84	168	17	52	85	45	226	
Capture rate in each site (100 net-nights)	179	146	32	488	160	132	240	131	
New records for Sarawak	0	0	1	0	0	1	1	0	
Total new records for sampling area	5	7	15	5	6	7	15	8	

Keys: *=new record for Sarawak, **= new record for study area, sg= sighted, TBC= Tubau camp, Bintulu, LHNP= Lambir Hills National Park, SNP= Similajau National Park, MM= Mount Murud, BANP= Batang Ai National Park, KNP= Kubah National Park, MPP= Mount Penrisen, Padawan, BNP= Bako National Park

Table 2. Current records and previous available literature on species found in the sampling sites

	TBC	LHNP	SNP	MM	BANP	KNP	MPP	BNP
Pteropodidae:								
Aethalops aequalis	0	0	0	1	0	0	1	0
Balionycteris maculata	1	1	1	1	1	1	1	0
Chironax melanocephalus	0	1	0	0	0	1	0	0
Cynopterus brachyotis	1	1	1	1	1	1	1	1
Cynopterus horsfieldii	0	0	0	1	0	1	1	0
Dyacopterus spadiceus	0	1	0	0	0	1	1	0
Megaerops ecaudatus	0	0	0	1	1	0	1	0
Penthetor lucasi	0	1	0	1	1	1	1	1
Pteropus vampyrus	0	0	1	0	0	0	0	1
Eonycteris major	0	1	0	1	0	1	1	0
Eonycteris spelaea	1	1	1	0	0	0	1	1
Macroglossus minimus	0	1	1	1	1	0	1	1
Emballonuridae:	TBC	LHNP	SNP	MM	BANP	KNP	MPP	BNP
Emballonura alecto	0	0	0	0	0	0	1	1
Emballonura monticola	0	0	0	0	0	0	0	1
Saccolaimus saccolaimus	0	0	0	0	0	0	0	1
Taphozous longimanus	0	0	0	0	0	0	1	0
Taphozous melanopogon	0	0	0	0	0	0	0	1
Megadermatidae:	TBC	LHNP	SNP	MM	BANP	KNP	MPP	BNP
Megaderma spasma	0	1	0	0	0	1	0	1
Nycteridae:	TBC	LHNP	SNP	MM	BANP	KNP	MPP	BNP
Nycteris tragata	0	0	0	0	0	0	0	1
Rhinolophidae:	TBC	LHNP	SNP	MM	BANP	KNP	MPP	BNP
Rhinolophus acuminatus	0	0	0	0	0	1	0	0
Rhinolophus affinis	0	0	0	0	0	1	1	0
Rhinolophus borneensis	1	1	1	1	0	1	1	0
Rhinolophus luctus	0	0	0	0	0	1	1	1
Rhinolophus philippinensis	0	0	0	0	0	0	1	1
Rhinolophus sedulus	0	1	1	1	0	1	1	0
Rhinolophus trifoliatus	0	1	1	0	0	1	0	1
Hipposideridae:	TBC	LHNP	SNP	MM	BANP	KNP	MPP	BNP
Hipposideros ater	0	0	0	1	0	1	1	1
Hipposideros bicolor	0	0	0	0	0	0	0	1
Hipposideros cervinus	1	1	1	1	0	1	1	1
Hipposideros cineraceus	0	0	0	0	0	0	1	1
Hipposideros coxi	0	0	0	0	0	0	1	1
Hipposideros diadema	0	1	0	0	0	1	0	1
Hipposideros doriae	0	0	0	0	0	0	1	0
Hipposideros dyacorum	0	1	1	0	0	1	1	1
Hipposideros galeritus	0	1	0	0	0	1	1	1
Hipposideros larvatus	0	0	0	0	0	1	0	1
Hipposideros ridleyi	0	1	1	0	0	1	0	0

Vespertilionidae:	TBC	LHNP	SNP	MM	BANP	KNP	MPP	BNP
Arielulus cuprosus	0	0	1	0	0	1	1	0
Falsistrellus petersi	0	0	0	0	0	1	0	0
Glischropus tylopus	0	1	0	0	0	1	1	0
Hesperoptenus tomesi	0	0	0	0	0	0	1	0
Hypsugo vordermanni	0	0	0	0	0	0	0	1
Kerivoula hardwickii	0	1	0	0	0	0	0	1
Kerivoula intermedia	0	1	0	0	1	0	1	0
Kerivoula minuta	0	1	0	0	0	1	1	0
Kerivoula papillosa	0	1	1	0	0	1	0	0
Kerivoula pellucida	0	1	1	0	0	1	0	1
Miniopterus australis	0	0	0	0	0	0	0	1
Miniopterus schreibersii	0	0	0	1	0	0	0	0
Murina rozendaali	0	0	0	1	0	1	0	0
Murina suilla	0	0	0	0	0	0	0	1
Myotis ater	0	0	0	0	0	1	0	1
Myotis adeversus	0	0	0	0	0	0	0	1
Myotis hasseltii	0	0	0	0	0	0	0	1
Myotis horsfieldii	0	0	0	0	0	1	0	0
Myotis muricola	0	0	1	0	0	1	1	1
Myotis ridleyi	0	1	1	0	0	1	0	0
Philetor brachypterus	0	1	0	0	0	0	0	0
Pipistrellus stenopterus	0	0	0	0	0	0	1	0
Pipistrellus tenuis	0	1	0	0	0	0	0	1
Tylonycteris pachypus	0	1	0	0	0	0	0	0
Tylonycteris robustula	0	1	0	0	0	0	1	0
No. Family	3	5	4	4	2	5	5	7
No. Species	5	28	16	14	6	32	32	33

Keys: 0= absence,1 = presence, TBC= Tubau camp, Bintulu, LHNP= Lambir Hills National Park, SNP= Similajau National Park, MM= Mount Murud, BANP= Batang Ai National Park, KNP= Kubah National Park, MPP= Mount Penrisen, Padawan, BNP= Bako National Park

Species diversity of bats in the selected sampling sites were compared to the other comparable studies by Hall (1996) in Gunung Mulu National Park, Salleh *et al* (1999) in the Kelabit Highlands, Hall *et al*. (2002) in Niah National Park, Tuen *et al*. (2002b) in Croker Range National Park and Mohd. Azlan *et al*. (2003) in Kayan Menterang National Park; Mohd. Azlan *et al*. (2005) in Bau limestone area and Mohd. Azlan *et al*. (2008) in Kubah National Park respectively. Hall (1996) listed 27 species of bats in Gunung Mulu National Park based on direct and indirect field observations and literature. This total was slightly lower than Bako National Park, Mount Penrisen, Kubah National Park and Lambir Hills National Park in terms of number of species recorded in the present study.

Salleh *et al*. (1999) recorded only five species of bats in the Kelabit Highlands. This is relatively low in terms of number of bat species compared with the montane sites of Mount Murud and Mount Penrisen in the present study. This could be due to the fact that only mist nets were used to capture bats during the survey. Mohd. Azlan *et al*. (2008) recorded a total of 21 species from lower elevation (119 asl) as compared to 15 species in higher elevation (787 asl) in the same study site (Kubah National Park) indicating that diversity of bat decreases as elevation increases. In Kayan Menterang National Park, only 11 species were recorded by Mohd. Azlan *et al*.

(2003) which is relatively low compared to other protected areas surveyed in this study. A comparable study in the limestone formations of Bau was conducted by Mohd. Azlan *et al*. (2005) and the area recorded a total of 23 species of bats, probably due to the extensive network of limestone caves present in the area. A study using field survey and published records of the Crocker Range National Park recorded the highest diversity of bats with 41 species (Tuen *et al*. 2002b).

Bako National Park, Mont Penrisen and Kubah National Park has similar number of species of bats with Niah National Park as 31 species were recorded there (Hall *et al.* 2002). Mount Murud and Mount Penrisen are higher in terms of number of species compared to the Kelabit Highlands but this might be due to the contrasting sampling efforts in these areas. Kubah National Park has high species composition as this area has been extensively surveyed by Hall *et al.* (2004) and further updated by Anwarali *et al.* (2008). The low diversity of bats at Batang Ai National Park is associated by the vegetation of the sampling site itself. Orchards have been known to cater fruit bats rather than insectivorous bats and the presence of tall forest in the vicinity of the area poses more problems in sampling bats because lack of capture of bats in cluttered forest type (Hall *et al.* 2004). Tubau camp is low in diversity of bats because this area is a logging camp and ongoing logging was rampant during the survey. Disturbed areas have been known to cater only several species that are more tolerant to human presence and disturbance. This includes *C. brachyotis* and *Rousettus* species that is known to thrive at agricultural plots in the Philippines (Mickleburgh *et al.* 1992).

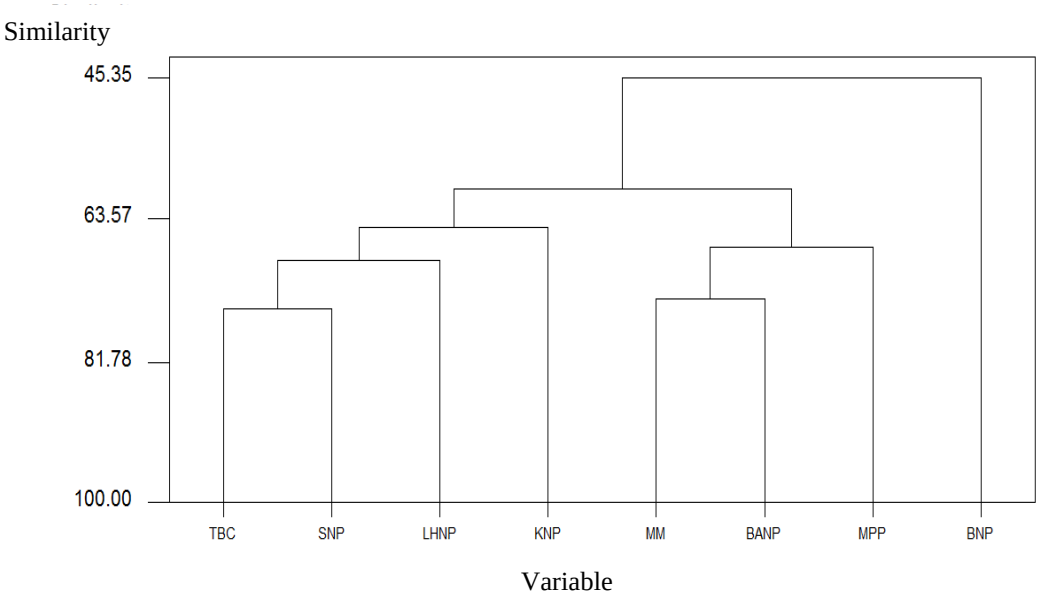

Figure 1. Study area similarity dendogram using UPGMA cluster analysis (clustering variables) based on the absence and presence of species data in the sampling sites showing two clusters of areas with similar bat diversity.

High abundance species like *C. brachyotis, Balionycteris maculata, R. borneensis, Pentetor lucasi, Macroglossus minimus, Eonycteris spelaea* and *H. cervinus* were found to inhabiting various areas and vegetation, from the lowland dipterocarp forest, *kerangas* to the higher elevation at the montane forest. Out of these seven species, *P. lucasi, E. spelaea, R. borneensis* and *H. cervinus* are cave bats that are found to occur throughout Borneo (Payne *et al.* 1985). Cave bats have important ecological role in the area they inhabit. The ecological niche of cave dwellers are also interrelated with the surroundings of the cave they inhabit and this include the forest adjacent to the caves. For cave bats survivability, this means they have an important ecological role in the vegetation surrounding the cave, and this includes effective food resource utilization available to them.

H. cervinus were found to utilise various types of vegetation including *kerangas* forest. *Kerangas* forest is poor in terms of faunal diversity, particularly

cicadas and moth diversity (Mackinnon *et al*. 1996). *C. brachyotis* is very successful, dominating most areas as the capture rate and its relative abundance was high which was similarly observed by Heaney (1986), Zubaid (1993), Nor (1996) and Hall *et al.* (2004). Generally *C. brachyotis* are found to roost in small groups in trees, under leaves, and in caves (Payne *et al* 1985). Although this species feeds on the fruits of 54 plant species, the leaves of 14 species and the flower parts of four species (Tan *et al*. 1998), Lim (1970) stated that *C. brachyotis* has two seasonal periods where they feed on fruits and then on floral parts. Recent data however, found that this species also relies on leaves (folivory) for food (Tan *et al.* 1998). *C. brachyotis* is an important seed disperser in secondary habitats and is considered an important seed disperser for many plants (Phua & Corlett 1989; Fujita & Tuttle 1991; Tan *et al.* 1998; Hodgkison *et al.* 2003).

Two species of fruit bats, *Aethalops aequalis* and *E. major* were found confined to higher elevations. This specialisation limits their distribution, as the data shows that the species are only found in three out of eight areas sampled. *Eonycteris major* often occurs sympatrically with *E. spelaea* but in very low numbers. *E. major* is considered to be rare and to be associated with primary forest (Mickleburgh *et al.* 1992). Although the results of this study showed that *E. major* is confined to higher elevation, Lim (1965) captured this species in rice field and rubber plantation at Kampung Pangkalan Kuap (South of Kuching) and Mohd. Azlan *et al.* (2006) also netted this species in the lowland dipterocarp forest at Loagan Bunut National Park. Both *Chironax melanocephalus* and *D. spadiceus* were found to be rare and occurred in very low numbers in observations by Start (1972b), Start (1975) and Hall *et al.* (2004). These bats have been recorded above the forest understorey (Start 1972b; Start 1975; Hall *et al.* 2004) and occur in low abundance. In the present study both species were caught in Lambir Hills National Park and Kubah National Park.

The microchiropteran community in Sarawak is particularly influenced by the forest type, availability of suitable roosting sites, species distribution and abundance. Most microchiropterans feed on insects that are palatable in relation to mouth size and Lim *et al.* (1972) observed that most microchiropterans feed on insects from the order orthoptera, coleoptera, diptera and hymenoptera. In another study by Jalaweh (2004), microchiroptera diet consisted of insects from 10 orders with hymenoptera and coleoptera being the integral part of their diet. Generally most microchiropterans that were caught were from the family Hipposideridae and Rhinolophidae. These two families were more abundant in survey captures than other families of microchiroptera found in Borneo. This observation was similar to previous studies (Start 1972a; Francis *et al.* 1984; Hall 1996; Hall *et al.* 2002; Nyaun *et al.* 2002; Shanahan & Debski 2002; Karim *et al.* 2004; Jayaraj *et al.* 2005; 2006; Anwarali *et al.* 2006a, 2006b).

Bats from the family Vespertilionidae are the most diverse group of bats in Borneo (Payne *et al.* 1985; Corbet & Hill 1992). This was exhibited in the captures, but most of the species were rare or occurred in small numbers and were hard to capture. Several species from the genera *Myotis* and *Kerivoula* were commonly captured as several representatives of these genera are widespread species. Species represented by singletons captured during the survey could be considered as rare but this could be misleading. This can be observed from the data for *H. larvatus* which was recorded only at one site but previous records shows that this species roost in caves and occur in large numbers (Hill 1959; Payne *et al.* 1985; Mohd. Azlan *et al.* 2005).

It was observed that all sampling sites had some degree of overlap in terms species composition and this was reflected by the availability of suitable habitat or other ecological requirements for these species. *C. brachyotis, B. maculata, R. borneensis, P. lucasi, M. minimus, E. spelaea* and *H. cervinus* have very general habitat and ecological requirements and can adapt to changes in the environment. For example even in the disturbed area in Tubau camp where the area was logged and replaced with *Acacia* species, certain species were able to survive and adapt with the severely altered environment. The cave dwelling species survived possibly because the roost habitat was still intact.

A high diversity of bats is found in tropical rainforest, and is directly influenced by the way the forest has been shaped to have a complex ecological interaction among its members (both plant and animal) of that ecosystem. Roubik (2005) described three basic principles of interaction that are present in the tropical rainforest in South East Asia: 1) coevolution, 2) ecological fitting and 3) loose niches. All three principles govern the diversity and generally the survival of the species in the tropical forest. The

diversity of plants in the tropical forest has been explained by Gillet (1962) and Losos & Leigh (2004) using the pest pressure hypothesis, where rarity or diversity is a product of specialisation and in the process it frees up space for its competitors to thrive in the same environment. This directly affects the diversity of plants resources that are found in the forests, and in turn will affect the bat community in general.

Such resources can have direct interaction with bats such as the interaction of nectarivorous bats (e.g. subfamily Macroglossinae) with flowers and other fruit bats with seeds and fruits, and indirect interaction such as the presence of insects that uses plant material that are preyed on by insectivorous bats. Different organisms also share resources with bats sharing these resources with birds, insects or other mammals. *Durio grandiflorus, D. oblongus* and *D. kutejensis* are examples of this phenomenon. These *Durio* species' flowers exhibit ornithophily and chiroperophily. *D. kutejensis* is especially associated with pollination by various pollinators, with giant honeybees, birds and bats all contributed to the effective pollination of this species (Yumoto 2005).

In general the disturbances and distribution of resources in the canopy are the main factors that affect the bats diversity in an area. Disturbance in an area is generally associated with habitat lost and can be either due to extraction of resources (Tubau camp), or human activities in the vicinity of the area (Batang Ai National Park). Other factors that influence a bat's distribution in a particular area include climatic conditions, fruiting and flowering season. In Peninsular Malaysia, more than 80% of the emergent and canopy tree species bloom in short periods of three and four months at irregular intervals, which usually of two to 10 years (Ashton *et al.* 1988; Appanah 1993). *Macroglossus* spp. are especially prone to the flowering seasonal effect as they pollinate plants from four families, which are Leguminosae, Loganiaceae, Sapotaceae (Momose & Karim 2005). Finally the deployment of nets, about 2 m in height, in the understorey also influences the overall recording of bat diversity in a particular area. This is attributed to the absence of several bats species which are associated with the canopy such as the *Rousettus, Dyacopterus* and *Pteropus vampyrus*. Several authors have also noted the differences of bat diversity at the canopy level and understorey highlighting the significance of sampling at the canopy level (Francis 1994; Abdullah & Hall 1997; Hodgkison *et al.* 2003).

CONCLUSION

The results of the study indicate that protected areas in Sarawak are rich and diverse in terms of chiropteran diversity, and montane areas that were unexplored previously hold distinct chiroptera composition that are different from the lowland. Severely logged-over areas pose a threat to the overall diversity of bats, with specialised habitat requirements. Overall the vegetation in terms of forest types, elevation and level of disturbance is a factor determining the diversity of bats in a particular area. The results of this study also indicate that the chiropteran diversity in Sarawak is still a large frontier to be explored, especially in terms of distributional information in unexplored or poorly sampled areas. More sampling is needed as the current study did not record all the species previously recorded in the study areas, thus indicating that the current effort was unable to document all the chiroptera species found in those sampling sites. The new records for Sarawak indicate that there are still bats presumably confined to Sabah that might be found in Sarawak and more surveys would reveal additional information on the bat composition in Sarawak.

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